A Study On Monitoring Overhead Impact on Wireless Mesh Networks

A. Hava, Yacine Ghamri-Doudane, J. Murphy

On Monitoring Overhead Impact in Wireless Mesh Networks

Adriana Hava*, Yacine Ghamri-Doudane* † ‡ and John Murphy*
*University College Dublin, School of Computer Science and Information, Belfield, Dublin 4, Ireland
† ENSIIE, 1 Square de la résistance, 91025 Evry CEDEX, France
‡ Université Paris-Est, LIGM Lab, 75420 Champs sur Marne
adriana.hava@ucdconnect.ie, ghamri@ensiie.fr, j.murphy@ucd.ie

***Abstract*—A wireless mesh network is characterized by dynamicity. It needs to be monitored permanently to make sure its properties remain within certain limits in order to provide Quality-of-Service to the end users or to identify possible faults. To establish in every moment what is the appropriate reporting interval of the measured information and the way it is disseminated are important tasks. It has to achieve information quickly enough to solve any issue but excessive as to affect the data traffic. The problem that arises is that the monitoring information needs to travel in the network along with the user traffic and thus, potentially causing congestion. Considering that a wireless mesh network has highly dynamic characteristics there is a need for a good understanding of the influences of disseminating monitoring information in the network along with user traffic. In this paper we provide an evaluation of the network performance while monitoring information is collected from network nodes. We study how different monitoring packet sizes and different reporting frequency of the information can impact the user traffic and compare these values to the case in which only user data travels across the network.**

I. Introduction

Wireless Mesh Networks (WMNs) have become very popular in the recent years. They offer a cost-efficient solution for Internet access and applications in both municipal deployments and short-term small range deployments. Also, due to multi-hop capabilities they can be used to provide wireless Internet access in areas where cellular coverage is limited. Another reason for the tremendous growth of WMNs is that they can operate in the ISM band which reduces significantly the deployment cost unlike other technologies that use licensed spectrum.

A WMN is composed of a static set of mesh nodes that perform routing, radio relaying, and traffic forwarding between the clients and gateways. Clients may include mobile terminals such as laptops, vehicular on-board-computers, or Wi-Fi enabled cellular phones.

Many research works focus on providing appropriate Quality-of-Service (QoS) in Wireless Networks in order to offer demanding applications, such as Voice over IP ([1]) or Video on Demand. These imply measuring certain network parameters to monitor the network performance and allowing the derivation of QoS levels that can be offered by the system. The information collected from the network can also be used for other purposes, such as identifying network failures or for locating network bottlenecks. In order to achieve this goal, an efficient monitoring system must be deployed. This enables fast reaction to any change occurring in the network.

Many solutions have been proposed in the past for efficient monitoring of wired networks [2], but they have not been designed with wireless mesh networks characteristics in mind. A study of these solutions shows they do not perform well in a wireless environment due to the dynamic nature [3], interferences or limited bandwidth, specific to a wireless system. An efficient monitoring system that can provide an accurate network view using real-time monitoring data is required for QoS provisioning or network failures identification. One issue related to monitoring traffic parameters is that the packets containing the collected information have to travel up to a central collection point and contend for the medium with the normal data traffic. Thus the monitoring packets count as an overhead to the network, causing degradation of data services and the overall network performance.

As stated in [4], monitoring implies two steps: the measurement of data, which can be active or passive, and the gathering of data, which can be classified into proactive or reactive. We consider a third phase, data dissemination, to be as important as the first two. This phase, which implies the reporting of the information collected by the mesh nodes to a collector, can be adjusted by changing the reporting frequency and the detail of reports. Therefore, in this paper we present a deeper analysis of the impact of monitoring on the performance of WMN through various simulations.

Section II describes the previous work done in this area and Section III presents our proposal for the evaluation of the monitoring overhead impact. The simulation setup used to assess the impact is described in Section IV. Finally, Section V discusses the evaluation results and Section VI presents the conclusions with some future work directions.

II. Related Work

There has been many solutions proposed for efficient traffic monitoring and adaptation ([5]) in wired networks [2]. However, traffic monitoring in wireless mesh networks has become a topic of interest for researchers only recently. In the following, we describe the major work that had been performed in this topic.

The authors in [4] propose a low overhead monitoring architecture customized for WMNs. Their approach is to automatically organize all nodes into a hierarchy of clusters dedicated to the delivery of monitoring data. Information is gathered while passively listening to the OLSR (Optimized Link State Routing) [6] protocol. The nodes in the structure cooperate and form a monitoring overlay which is able to adapt to the network characteristics. The evaluation is done using two performance metrics: robustness and scalability. The work in [4] lacks in evaluating the proposed method in the presence of user traffic. This traffic may suffer interference from the monitoring data that is transmitted in the network.

In [7], Kim et al. introduce a scheme for accurate measurement of link quality in WMNs. Efficient and Accurate link-quality monitoR (EAR) uses three measurement schemes: passive, cooperative, and active monitoring. Their proposed solution maximizes the measurement accuracy by adopting dynamically one of the three schemes. The dissemination of link-quality information is not analyzed, thus it is unknown how the monitoring data interferes with the user traffic.

A probe-based monitoring architecture for IP flows in a WMN is presented in [8]. MeshFlow records are created on every mesh node on the path of a packet. These records are exported to a dedicated collector, which analyzes the data. The authors mention three methods for transmitting the records: dedicated cable line, antennas deployed around the entire backbone network, or in a multi-hop fashion along with the normal traffic transport. The first two methods increase the cost of deployment while the last method introduces overhead which is not analyzed in the paper.

Another method to reduce the overhead traffic is to identify the optimal placement of monitoring nodes. Chaudet et al. in [2] found that in terms of deployment costs it may be more advantageous to monitor only 95% of the traffic, thus reducing the number of probes required. The work presented in [9] describes WiMFlow, a self-organized monitoring framework for WMNs. The proposed mechanism adapts the packet rate of control messages based on the topology changes in order to keep the overhead low.

Although all the above papers present different methods for collecting monitoring information they do not study the impact of disseminating this data. The studies presented in [10] are the only ones which investigate this problem. The authors study the effects of monitoring overheads on the forwarding of users FTP data traffic. They also check how it impacts the wireless mesh network performance in terms of packet loss and throughput. Three different approaches are presented: the monitor-selection, reporting interval, and threshold-based monitoring approach. For each of them the aggregated packet-loss percentage, end-to-end delay and percentage of packets retransmissions at the link layer are computed. We consider the aforementioned evaluation to be incomplete as some details are omitted: there is no mention about the number of wireless interfaces on each mesh node, about the chosen monitoring packet size for the approaches presented, and the most important, their results are not compared against the case when the monitoring is not enabled. Also we see a limitation in the assumption whether the monitoring packet size and reporting frequency should be connected. In our work, we disconnect the two parameters and analyze the impact on the user traffic if, for example, a larger packet is sent at low or high frequencies.

III. Network Model and Evaluation Methodology

We consider that the most sensitive applications to networks fluctuations, but also the ones that require continuous monitoring, are video and voice data. Therefore, we focus our attention on the impact of disseminating the monitored information as overhead to UDP client traffic.

A. Network Model

Each mesh node is equipped with two 802.11g antennas for communication between mesh nodes and one 802.11a antenna for communication with the clients. We chose 802.11g for the communication inside the mesh network because of its larger distance range which is more suitable for an urban scenario. The 802.11a protocol was chosen for clients' connectivity because of the increased non-overlapping available channels.

For the mesh networking model we use the 802.11s standard and Hybrid Wireless Mesh Protocol (HWMP) as the MAC-layer routing protocol. The 802.11s standard is an extension of the 802.11 for arbitrary multi-hop topologies, where each mesh node operates as a link-layer router and cooperates with all the other mesh nodes in the process of frame forwarding. HWMP is based on the AODV routing protocol, but it works at the MAC layer for efficient path selection. HWMP works in two modes: proactive and reactive. In the reactive mode the path discovery starts when a source has data to transmit to an unknown destination. In the proactive mode a single mesh node is configured as root and if the route to a destination is unknown the data is sent to the root node which is responsible for forwarding it to the destination node.

B. Evaluation Methodology

The impact of monitoring data dissemination is evaluated through three different metrics: throughput, packet loss, and packet delay. These parameters are measured while varying the reporting frequency of measurement information and by varying the monitoring packet size. A more frequent reporting interval gives a better view about the network performance but it has a greater impact on the user traffic (because of higher contention for the medium). While in the case of a larger reporting interval the information granularity might be insufficient to perform real-time adaptation.

Therefore, this work gives a better insight of what is the trade-off of choosing between different combinations of monitoring packet sizes and reporting frequencies.

IV. Evaluation Results

A. Simulation Setup

NS-3, a discreet-event open-source network simulator, is used in our simulation setup. The topology on which the simulations are run is presented in Figure 1.

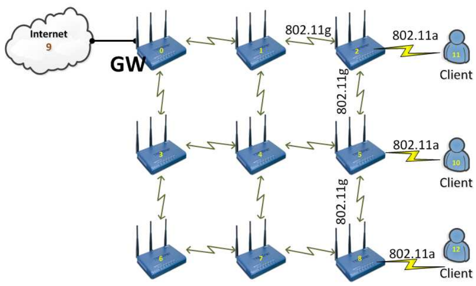

Fig. 1. Nine-node grid topology

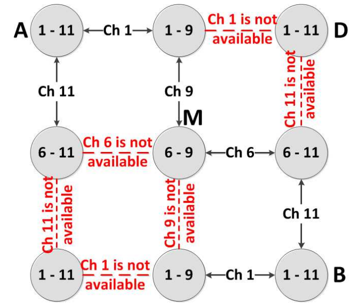

Fig. 5. Tiered channel allocation

Our two configurations are a 3x3 and a 4x4 grid topology consisting of mesh nodes placed at 100m grid step. The gateway is the node at the top-left of the grid. For the channel allocation we used two different configurations: spread channel policy, where different non-overlapping 20 MHz frequency channels are assigned to different mesh node interfaces, and a tiered channel distribution, where the channels are allocated as in Figure 5. Two types of mesh nodes are evaluated: equipped with one interface and with two interfaces.

In our simulation setup, the clients are spread across the wireless mesh network. User data packets are set at 1500 Bytes with different frequencies of sending data, equivalent to a user demand of 0.25, 0.50, 0.75, 1.00 and 1.25 Mbps for each client. The Nakagami fast fading propagation model is used, since it is suitable for urban scenarios for which our monitoring evaluation is designed.

For the monitoring traffic we chose reporting frequencies from the following values: 0.5, 1, 5, 10, and 15 seconds and the monitoring packet size was varied between 500, 1000, and 1500 Bytes. We decided to choose these reporting frequencies to have a larger variety of values and also based on other studies where the most common used value for reporting interval is one second. In summary, our configuration is presented in Table I.

TABLE I
SIMULATION PARAMETERS

Grid Topology	HWMP Mode	Channel Allocation	No. of Interfaces	Data Packet Size	Channel Rate	Reporting Frequency	Monitoring Packet Size
3x3 4x4	Reactive Pro-active	Spread Tiered	1 2	1500 Bytes	6 Mbps	0.5 sec 1.0 sec 5.0 sec 10.0 sec 15.0 sec	500 Bytes 1000 Bytes 1500 Bytes

The results from Figure 2 depict the case of nine node grid where each user has a demand of 0.25 Mbps, Figure 3 for 0.75 Mbps user demand, and Figure 4 for 1.25 Mbps demand per user. These cases are chosen in order to evaluate the impact of reporting monitoring information in three different network traffic demand situations: for a low, medium, and high traffic volume.

All the figures present the average values for the overall throughput, end-to-end delay, and packet loss over five different simulation runs. The error bars represent the confidence interval.

The values represented with black bars are obtained when the monitoring reporting functionality is disabled. The green-tone bars show the average values obtained when the monitoring reporting functionality is enabled on all mesh nodes.

Each green bar indicates an average value obtained for a specific frequency from 0.5 seconds to 15 seconds, as per legend. Each set of five green bars corresponds to a monitoring packet size (PS) of 500 Bytes, 1000 Bytes and, respectively, 1500 Bytes. The upper plot of the figure indicates the impact on the user throughput when the monitoring reporting functionality is enabled. The middle plot depicts the impact on the end-to-end user delay, while the bottom plot indicates the impact on packet loss.

For the first case, where the user demand is 0.25 Mbps (Figure 2), it can be observed that for some cases, the reporting of monitoring data does influence the amount of throughput the clients receive. This situation happens when the *spread channel allocation* is used, for both reactive and proactive routing protocol, and for either one or two interfaces per node. It can be observed that when the frequency of reporting is the highest, i.e. 0.5 seconds, also the throughput drops faster compared with the case when the reporting frequency is set to lowest, i.e. 15 seconds. The same behaviour can be observed when measuring the end-to-end delay. If the frequency of reporting is set to lower values, the end-to-end delay increases compared to the case of higher reporting frequency. For the case of reactive routing, the end-to-end delay increases by up to 30% compared with the case when the reporting functionality is disabled.

In terms of packets lost, it can be observed that the size of the packets containing the monitoring data plays an important role. In the case of *spread channel allocation*, for smaller packets, i.e. 500 Bytes, the amount of packets lost is smaller compared to the case when packets of 1500 Bytes are used to transfer the monitoring information. It can be observed that the packet loss rate increases up to 10% when 500 Bytes packets are used and up to 30% when 1500 Bytes packets are used to encapsulate the information.

For the *tiered channel allocation* configurations, described in Figure 5, it can be observed that the impact on the throughput is much smaller compared to the case of spread channel allocation. The end-to-end delay maintains at the same

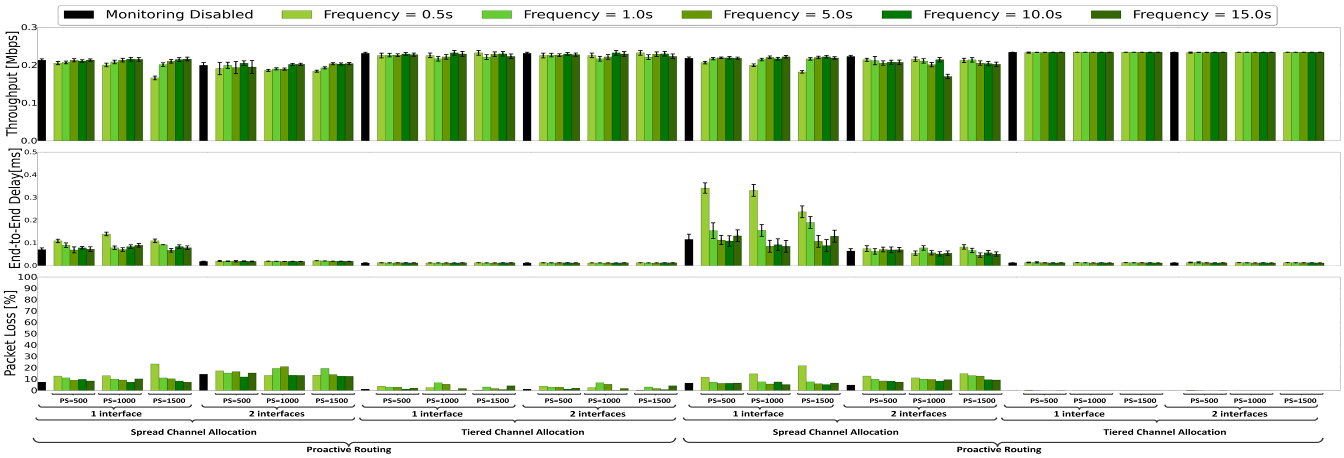

Fig. 2. Simulation results for a 3x3 grid and 0.25 Mbps demand per user

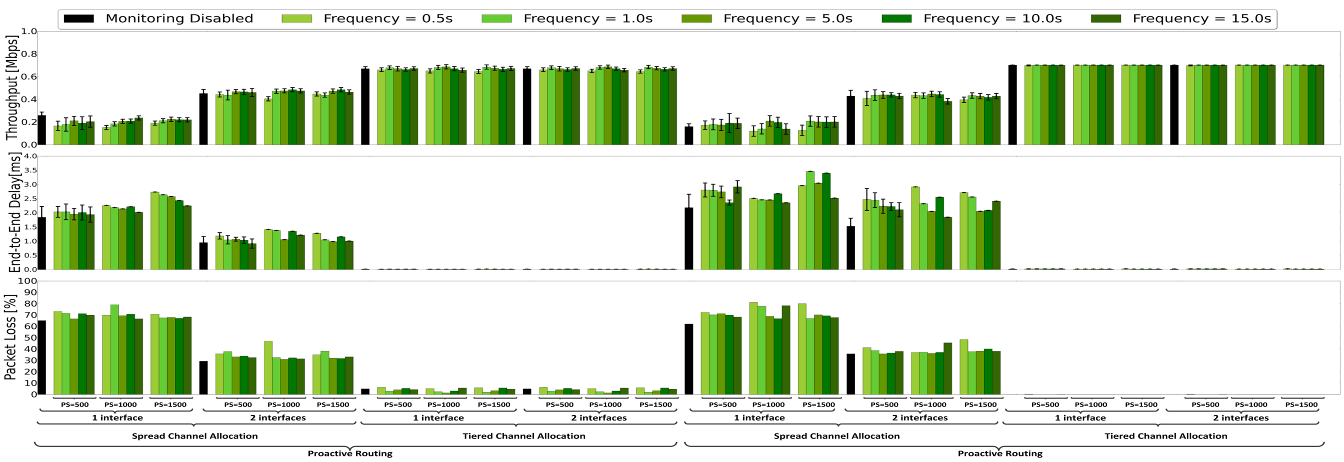

Fig. 3. Simulation results for a 3x3 grid and 0.75 Mbps demand per user

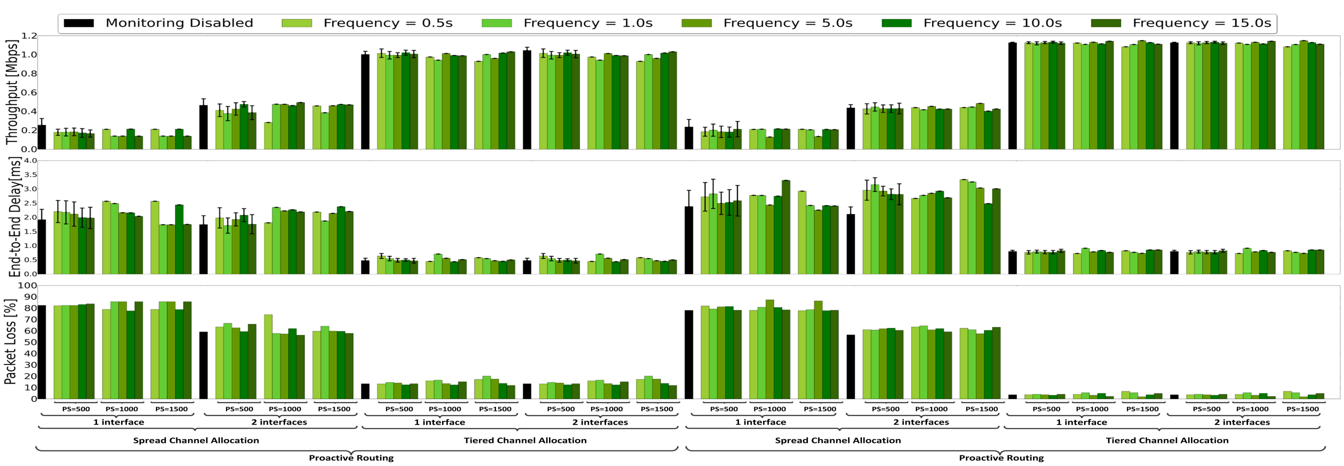

Fig. 4. Simulation results for a 3x3 grid and 1.25 Mbps demand per user

value as when the reporting monitoring data functionality is disabled. A small increase in packet losses can be observed in the bottom plot, occurring only in the case of proactive routing.

Figure 3 depicts the results for 0.75 Mbps demand per user. A drop in throughput can be observed for all the configurations, but the highest impact is on the end-to-end delay. For all the configurations, the end-to-end delay increases compared to the case when the reporting functionality is not enabled. The highest impact is observed when the packet containing the monitoring information is set to 1500 Bytes.

Figure 4 presents the results for a user demand of 1.25 Mbps. The impact of sending monitoring data over the mesh network has a higher impact on the user throughput compared to the other two scenarios. On all configurations it can be observed an important decrease in throughput when the reporting functionality is enabled.

In order to have a deeper understanding on how reporting the information collected by each node to a central server will impact the clients, we extend the simulations on a 16 node mesh grid. The results are presented in Figure 6 and Figure 7.

It can be observed in Figure 6 for proactive routing and spread channel allocation configuration that the impact on the user throughput is much higher. For higher reporting frequencies, i.e. 0.5 seconds, the throughput drops by up to 20% compared to the case where there is only the client traffic running in the network. It can also be noticed a dependency on the size of the packet which is carrying the monitoring information. For larger packet sizes, i.e. 1500 Bytes, the throughput drops even more, up to 30%, compared to the case of 500 Bytes for the monitoring packet.

The end-to-end delay is also affected by the monitoring data dissemination through the network. The delay for the user packets will be higher for lower reporting frequencies and vice-versa. In one or two interfaces per node scenarios, the *tiered channel allocation* configuration has the same impact. The channel distribution allows the two interfaces to communicate independently of each other. However, if we consider the continuous path presented in Figure 5 between node A and node B, node M is not able to support another path between the two nodes as its both channels are involved for the initial path. This means that node B will behave as a single-channel node. Other possible routes between A and B could be established through nodes C or D but their channels are not available.

B. Discussions and Lessons Learned

Our study allowed us to highlight four main conclusions regarding the effect of the monitoring reporting functionality on the user traffic performance:

- The monitoring data reporting frequency plays an important role on the user traffic performance. In all the configurations presented, it has been observed that if the reporting frequencies are set to high values also the impact on the end-user traffic performance will increase. This can be observed in the measured throughput values which will be smaller compared to the case when the reporting functionality is disabled. Also the end-to-end delay is similarly strongly affected. For higher reporting frequencies the time a packet will spend in the mesh network will be longer. When the reporting frequency is set to high values, i.e. 15 seconds, the impact is almost zero.
- Along with the reporting frequency, a role is also played by the size chosen for the packet carrying the collected monitoring information. If the size of the monitoring packet is large, the impact on the user traffic performance is high. The packet size is strongly connected with the reporting frequency chosen. The highest impact on the user traffic performance has the combination of a large monitoring packet size and a high reporting frequency. The throughput and the end-to-end delay are both affected in this case. Most importantly, the impact of the packet size is visible only for few cases, while the increase in the reporting frequency importantly impacts the user traffic performances for most of the studied wireless mesh network configurations.
- Both low traffic networks, i.e. 0.25 Mbps user demand, and congested networks, 1.25 Mbps user demand, are affected similarly by the presence of monitoring data. This means that even if the network is not congested, the reporting of monitoring data has a negative impact on the user traffic performance.
- The impact of the reporting of monitoring data is obviously increased when the network size increases. Comparing the 3x3 grid case and the 4x4 grid case, it can be observed a more important decrease in the throughput and increase in the end-to-end delay in the 4x4 grid case when the monitoring reporting functionality is enabled.

These results allow us to state that in order to mitigate the effect of the reporting of the monitoring data, there is a clear need to design new approaches that reduce the frequency of monitoring by enabling only some well selected nodes to perform the monitoring task. These nodes need to correctly adapt their reporting frequency.

V. Conclusions And Future Works

The paper presents a study about the impact of disseminating the monitoring information encapsulated into packets along with the user traffic. First, we analyze the user throughput, packet delivery ratio, and the packet delay when the monitoring functionality is disabled. Second, we study how these parameters change for various combinations of monitoring packet sizes and reporting frequencies on different mesh network configurations.

Most of the previous works look at different measurement techniques in wireless mesh networks but have omitted to analyze the consequences of disseminating the collected information along with the user data traffic. Thus, our work gives a deeper analysis of this problem.

Based on a number of simulations we show that there is a significant impact on the user traffic. We analyze how the network performance changes for various reporting frequencies and monitoring packet sizes.

Part of our future work will be to use these results for proposing new mechanisms to adapt the number of monitoring nodes based on the network conditions and also to modify in time the mesh nodes' reporting frequencies independently of each other.

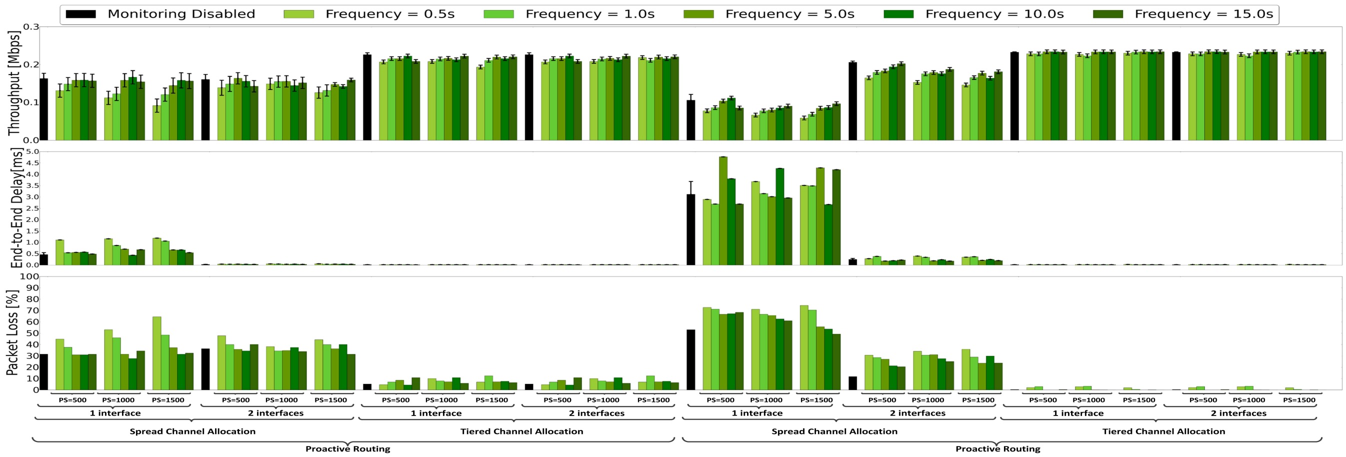

Fig. 6. Simulation results for a 4x4 grid and 0.25 Mbps demand per user

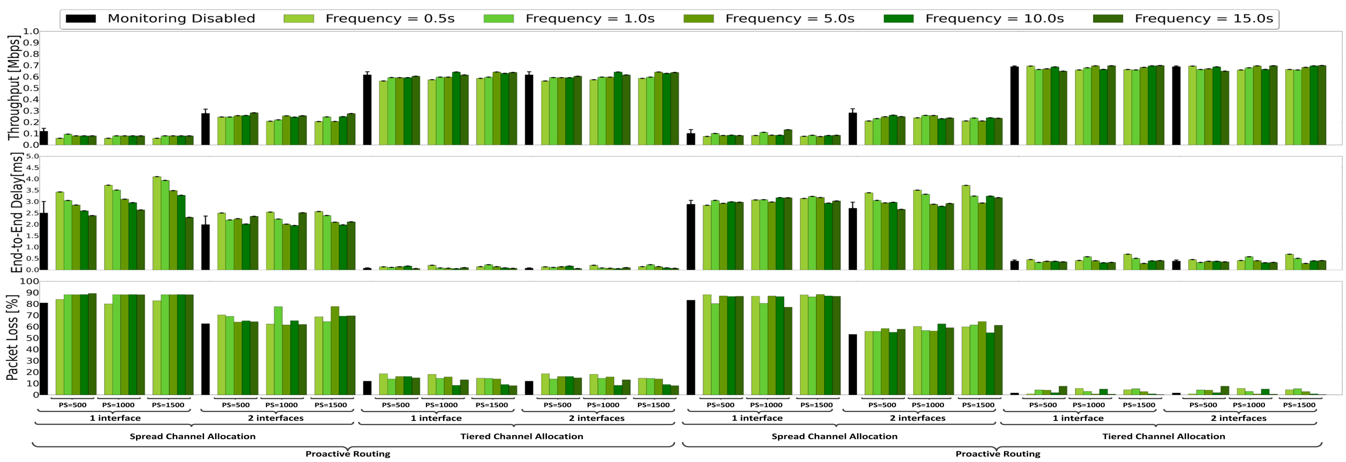

Fig. 7. Simulation results for a 4x4 grid and 0.75 Mbps demand per user

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References

[1] C. Olariu, J. Fitzpatrick, P. Perry, and L. Murphy, “A Qos Based Call Admission Control And Resource Allocation Mechanism For Lte Femtocell Deployment,” in *Consumer Communications and Networking Conference (CCNC), 2012 IEEE*, jan. 2012, pp. 884 –888.

[2] C. Chaudet, E. Fleury, I. Lassous, H. Rivano, and M. Voge, “Optimal Positioning Of Active And Passive Monitoring Devices,” in *Proceedings of the 2005 ACM conference on Emerging network experiment and technology*. ACM, 2005, pp. 71–82.

[3] B. Ishibashi and R. Boutaba, “Topology and mobility considerations in mobile ad hoc networks,” *Ad hoc networks*, vol. 3, no. 6, pp. 762–776, 2005.

[4] F. Sailhan, L. Fallon, K. Quinn, P. Farrell, S. Collins, D. Parker, S. Ghamri-Doudane, and Y. Huang, “Wireless Mesh Network Monitoring: Design, Implementation And Experiments,” in *Globecom Workshops, 2007 IEEE*. IEEE, 2007, pp. 1–6.

[5] G. Muntean and L. Murphy, “Adaptive Pre-Recorded Multimedia Streaming,” in *Global Telecommunications Conference, 2002. GLOBECOM’02. IEEE*, vol. 2. IEEE, 2002, pp. 1728–1732.

[6] T. Clausen and P. Jacquet, “Optimized Link State Routing Protocol (OLSR),” RFC 3626 (Experimental), Internet Engineering Task Force, Oct. 2003. [Online]. Available: http://www.ietf.org/rfc/rfc3626.txt

[7] K. Kim and K. Shin, “On Accurate Measurement Of Link Quality In Multi-Hop Wireless Mesh Networks,” in *Proceedings of the 12th annual international conference on Mobile computing and networking*. ACM, 2006, pp. 38–49.

[8] F. Huang, Y. Yang, and L. He, “A Flow-Based Network Monitoring Framework For Wireless Mesh Networks,” *Wireless Communications, IEEE*, vol. 14, no. 5, pp. 48–55, 2007.

[9] C. Popi and O. Festor, “Wimflow: A Distributed, Self-Adaptive Architecture For Flow Monitoring In Wireless Mesh Networks,” in *Network Operations and Management Symposium (NOMS), 2010 IEEE*. IEEE, 2010, pp. 9–16.

[10] D. Gupta, D. Wu, P. Mohapatra, and C. Chuah, “A Study Of Overheads And Accuracy For Efficient Monitoring Of Wireless Mesh Networks,” *Pervasive and Mobile Computing*, vol. 6, no. 1, pp. 93–111, 2010.